Facility Strategy

RHIC performance overview

Luminosity and polarization evolution
(towards "enhanced luminosity")

Future upgrades
- EBIS
- RHIC luminosity upgrade
- eRHIC

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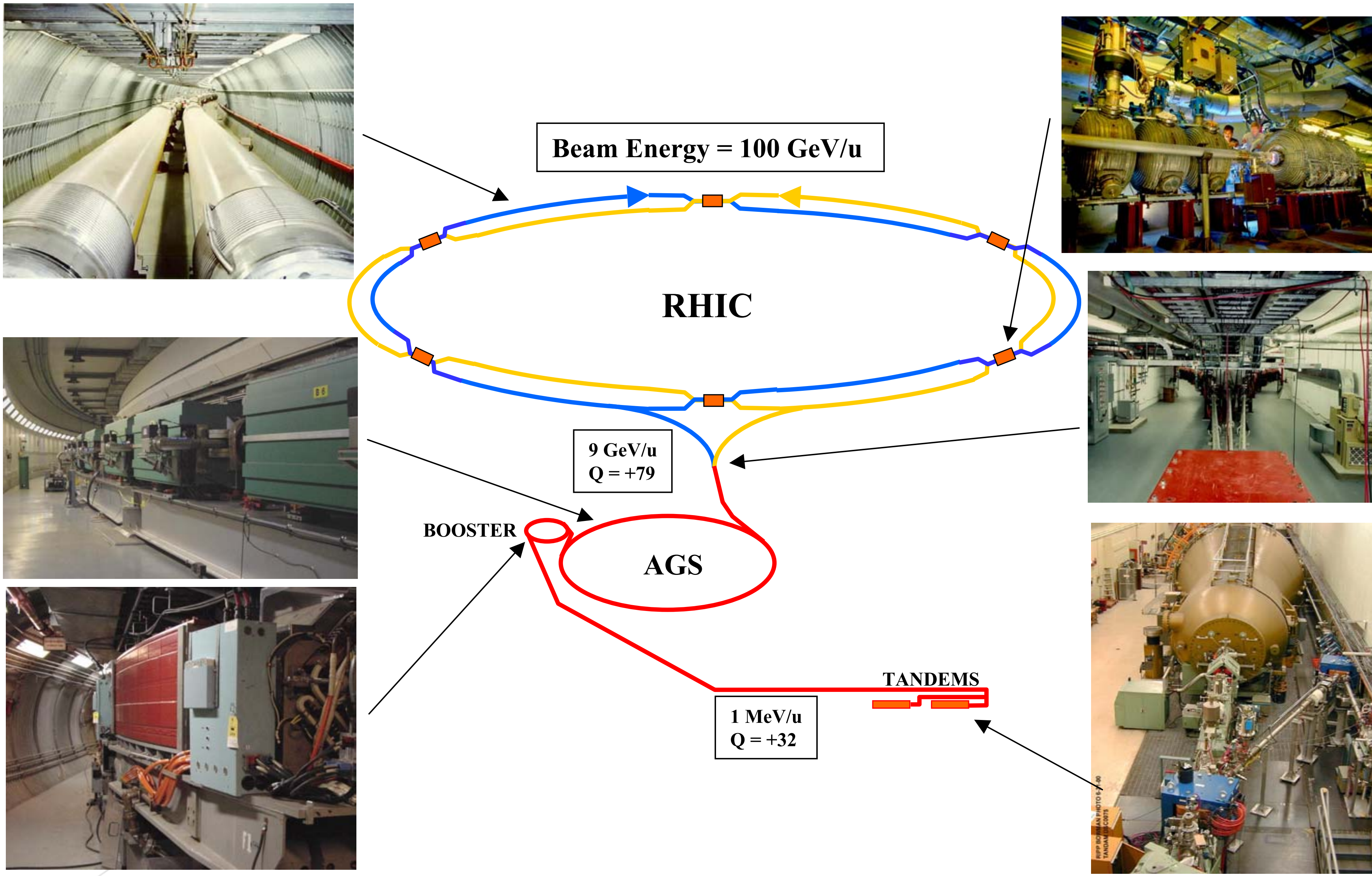
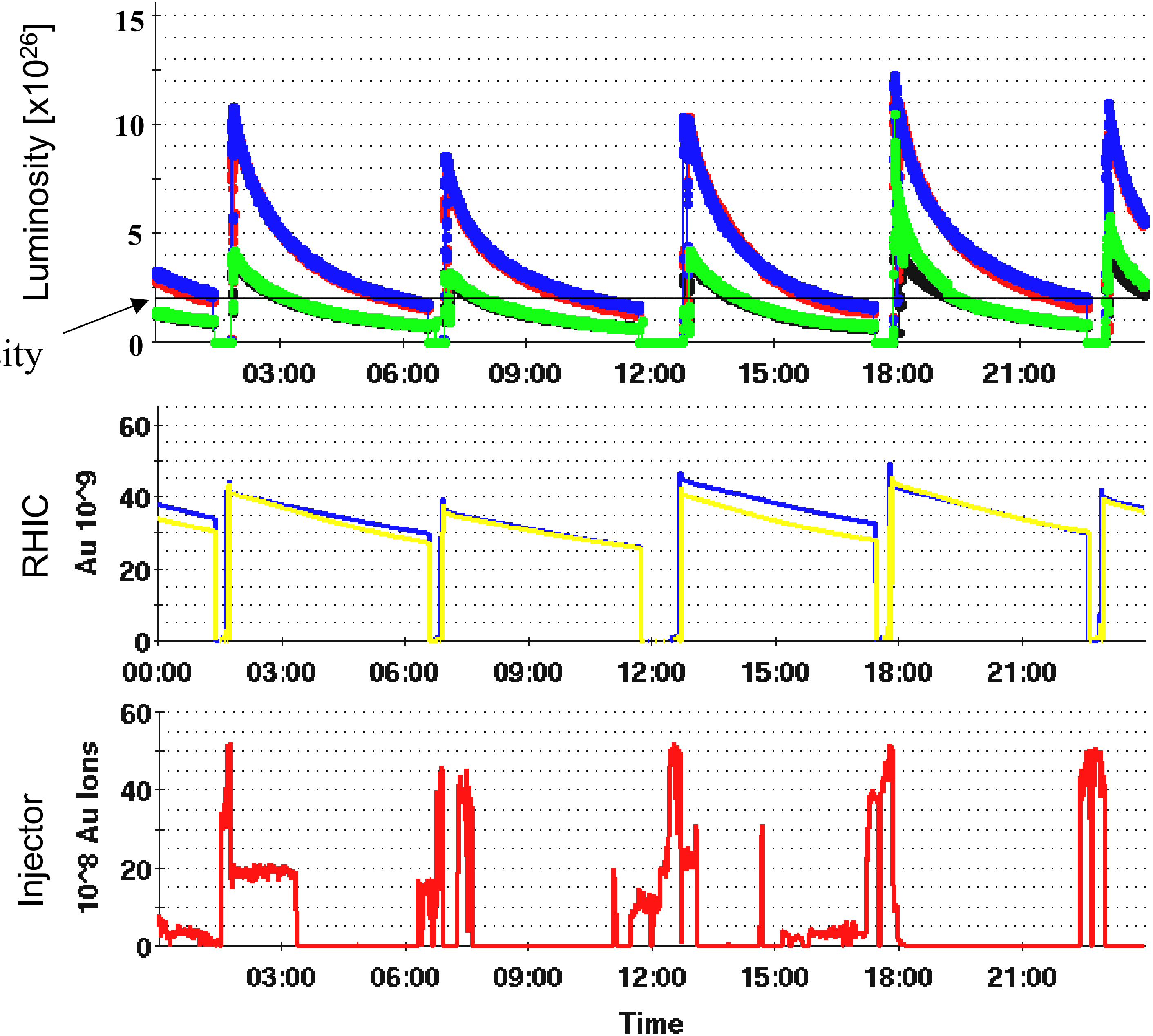
Thomas Roser
NSAC subcommittee
April 4, 2005

Gold Ion Collisions in RHIC

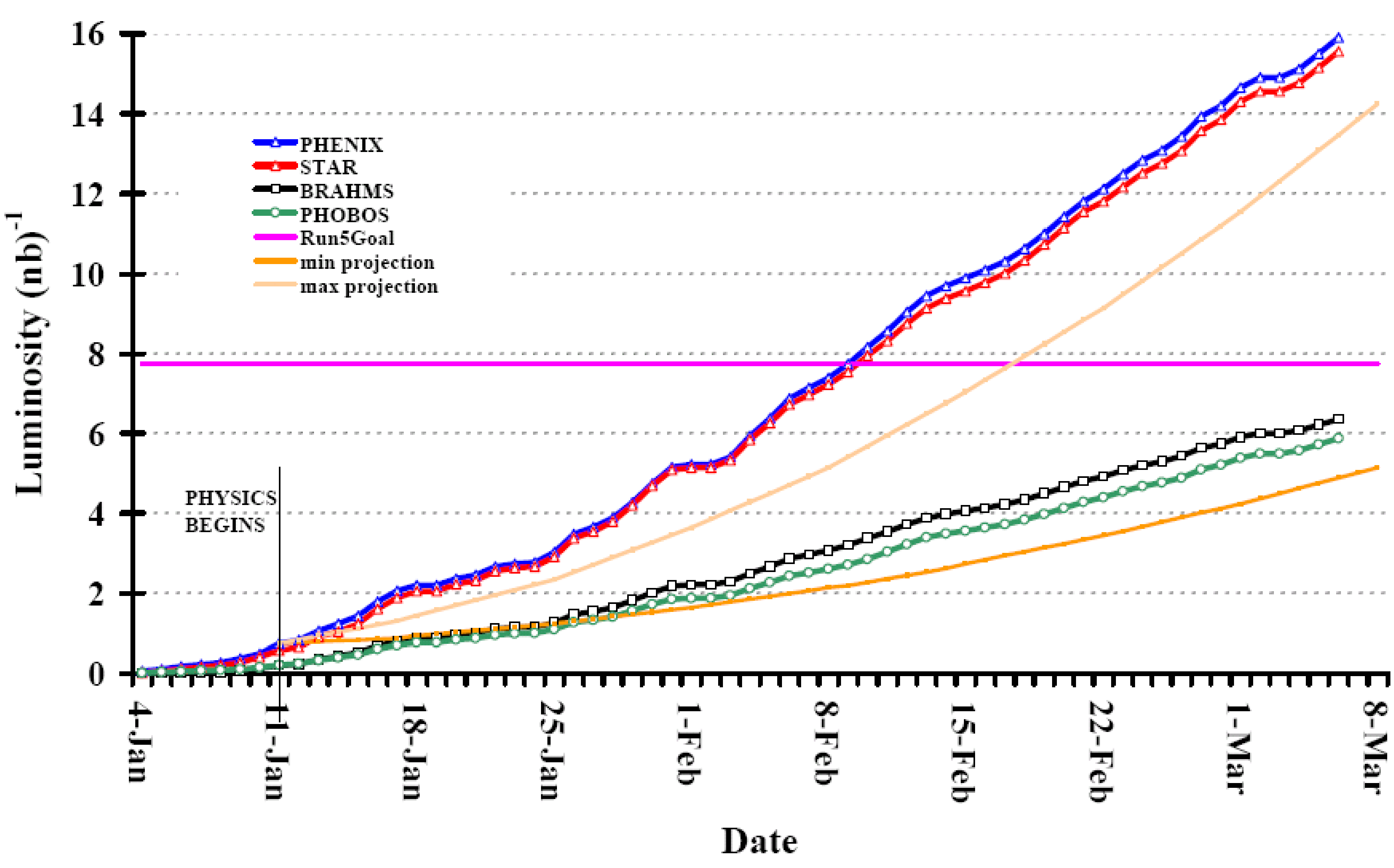


RHIC Au-Au performance – 2 x design luminosity



design luminosity

RHIC Run 5 Delivered Cu-Cu Luminosity



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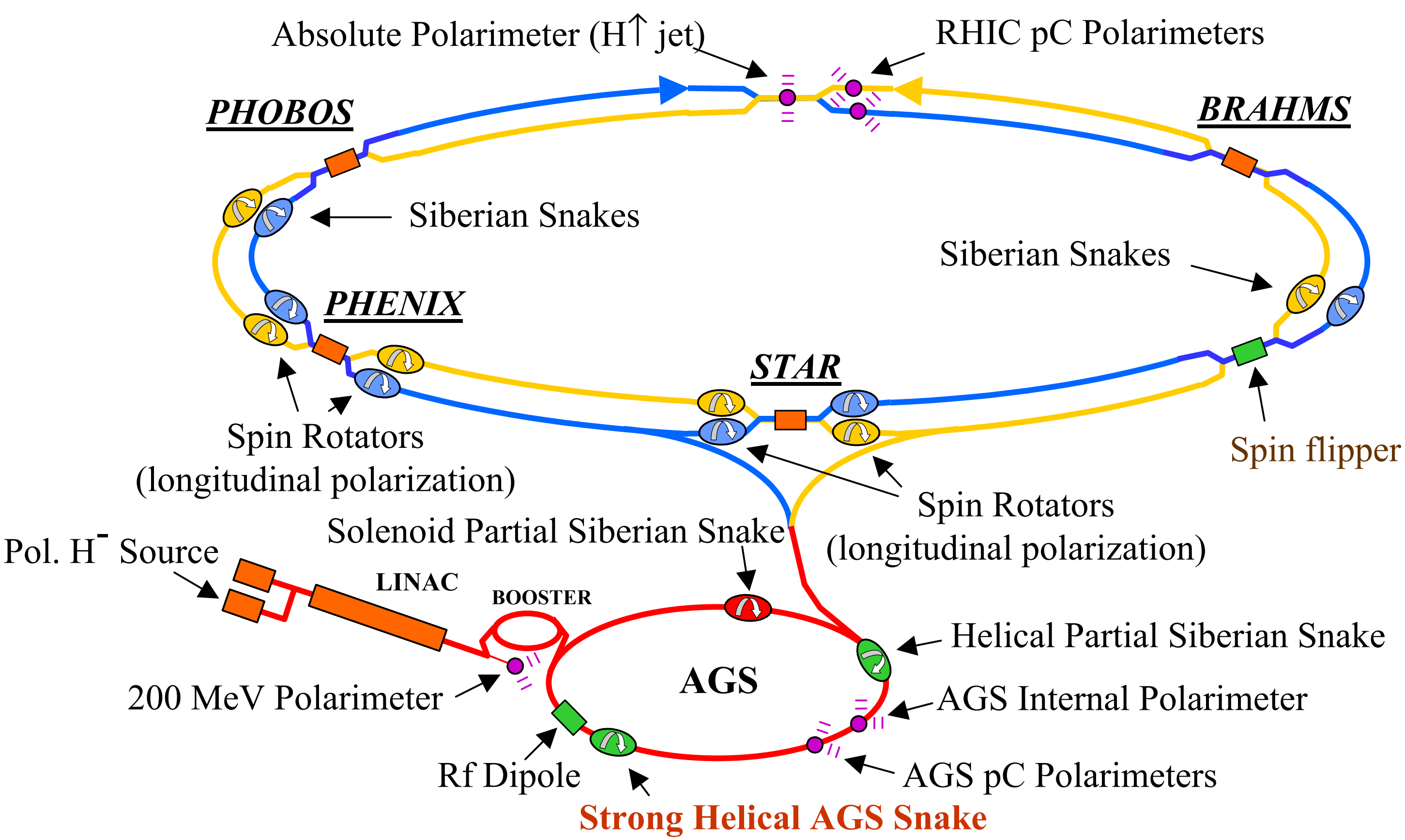
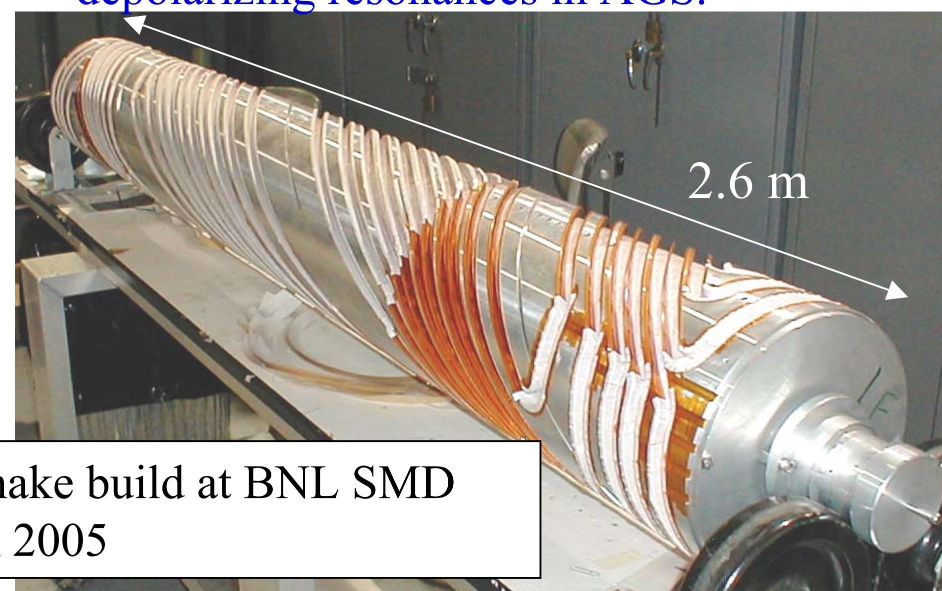
RHIC polarized proton accelerator complex



New AGS helical snakes

5 % helical snake build at Tokana Industries funded by RIKEN.

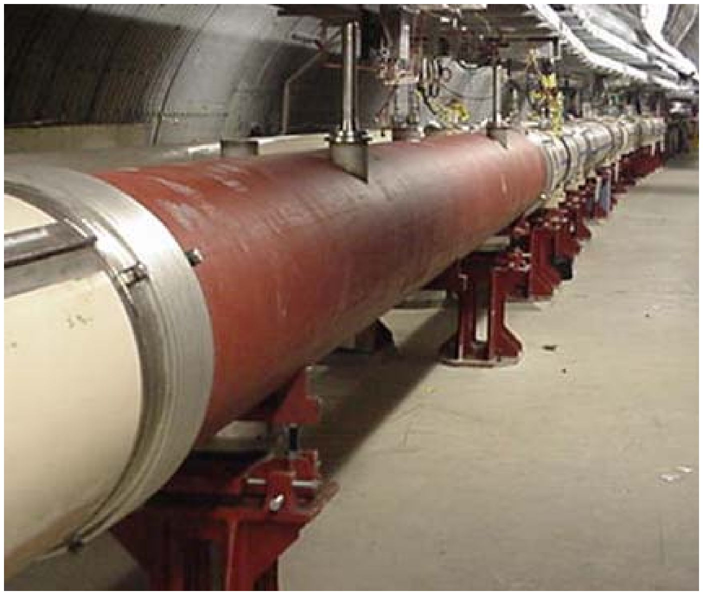
- Warm snake avoids polarization mismatch at AGS injection and extraction.
- Cold strong snake eliminates all depolarizing resonances in AGS.

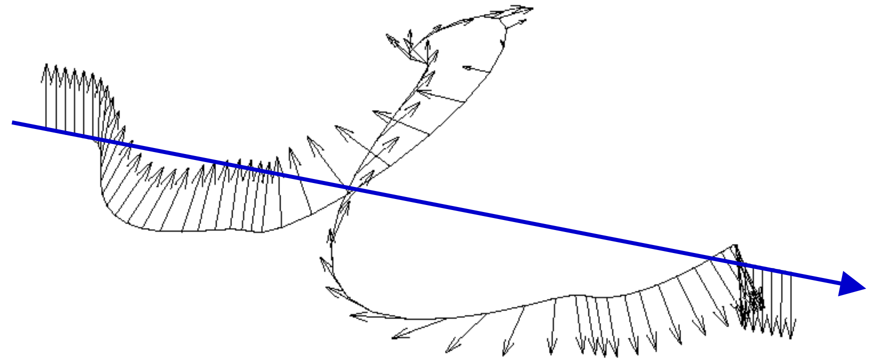


30% s.c. helical snake build at BNL SMD
Installed in March 2005

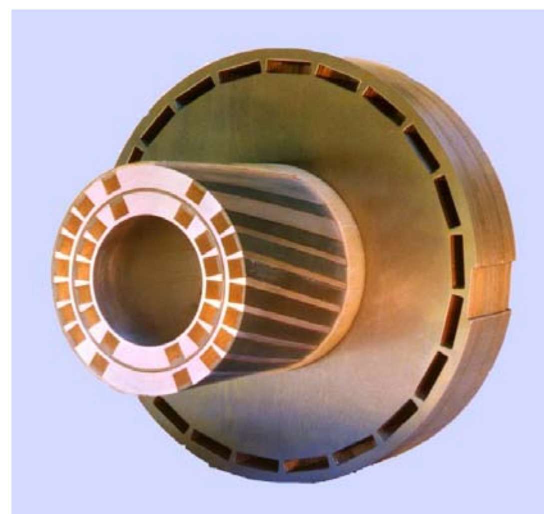
Siberian Snake in RHIC Tunnel

Siberian Snake: 4 superconducting helical dipoles, 4Tesla, 2.4 m long with full 360° twist

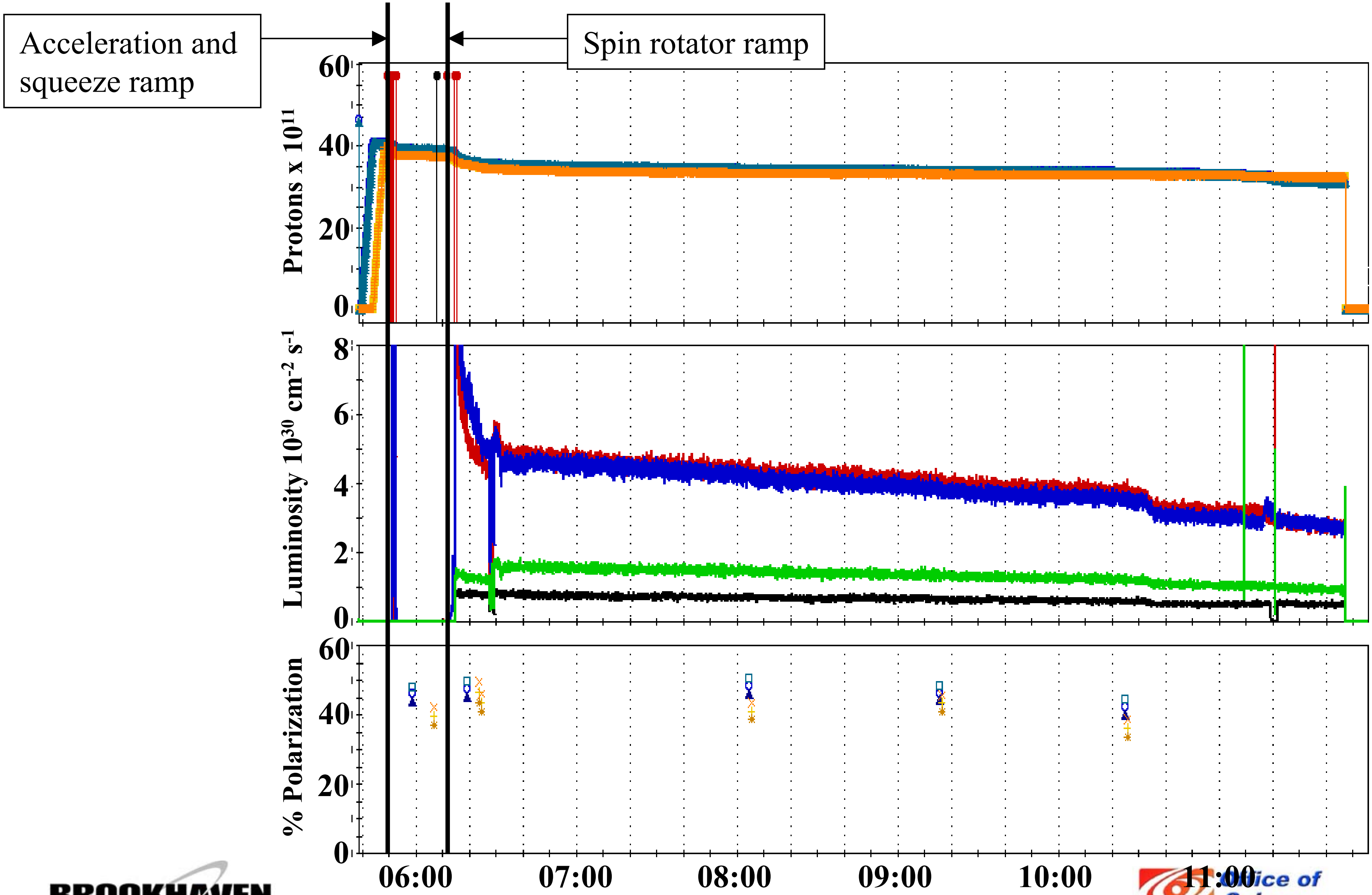




Funded by RIKEN, Japan
Designed and constructed at BNL



Polarization survival in RHIC



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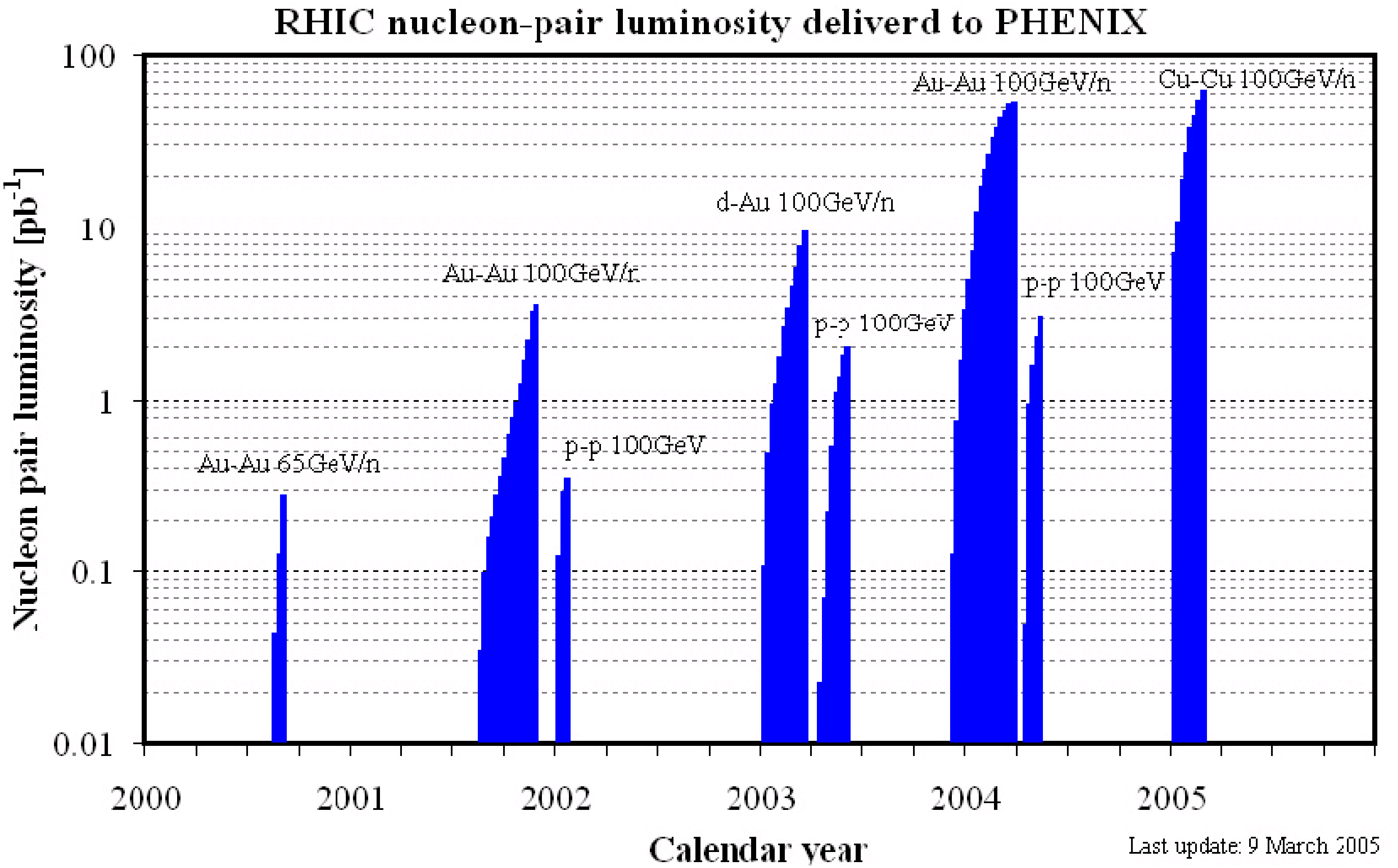
RHIC – a Uniquely Flexible High Luminosity Collider

(Nucleon-pair luminosity $A_1 A_2 L$ allows comparison of different species)



Luminosity increased by 2 orders of magnitude in 4 years.

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RHIC Accelerator Complex Operations

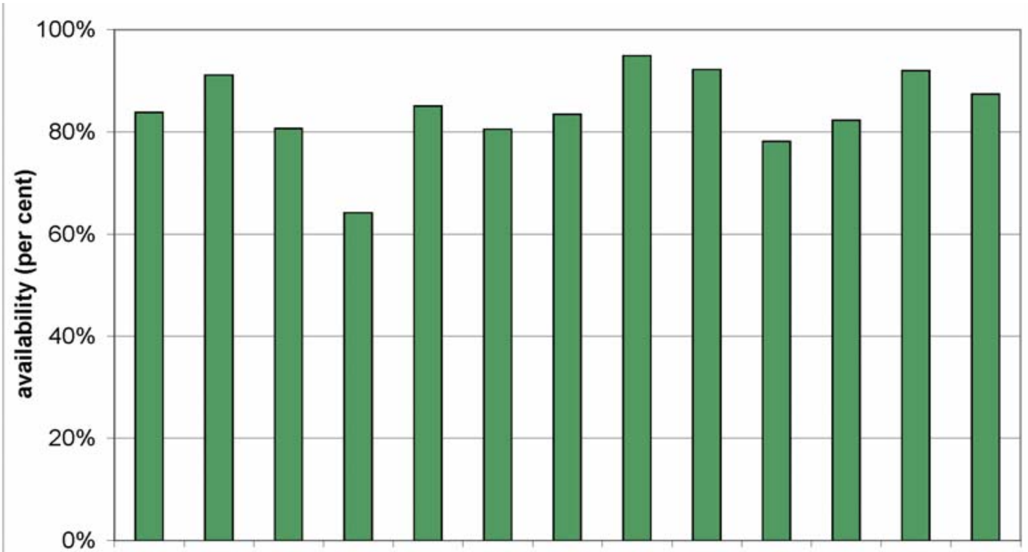
7 major accelerator systems (2 Tandems, Linac, Booster, AGS, 2 RHIC rings) consisting of:

- 6 miles of evacuated beam lines (large part of it below 10^{-10} Torr)
- 4.5 miles of superconducting magnets and cryostat
- 25 kW@4.5K He refrigerator (12 turbines, 25 compressors,…)
- 2 rapid cycling synchrotrons (±16 MW and ± 40 MW power supplies)
- 42 high power rf systems (0.1 – 200 MHz)
- 1300 programmable DC power supplies
- 54 pulsed power systems

FY05 operations budget ($95M, equal to the recommendation of $95M [2005$] from 2002 RHIC operations review) is sufficient for safe and efficient operation of 31 cryo-weeks with excellent availability.

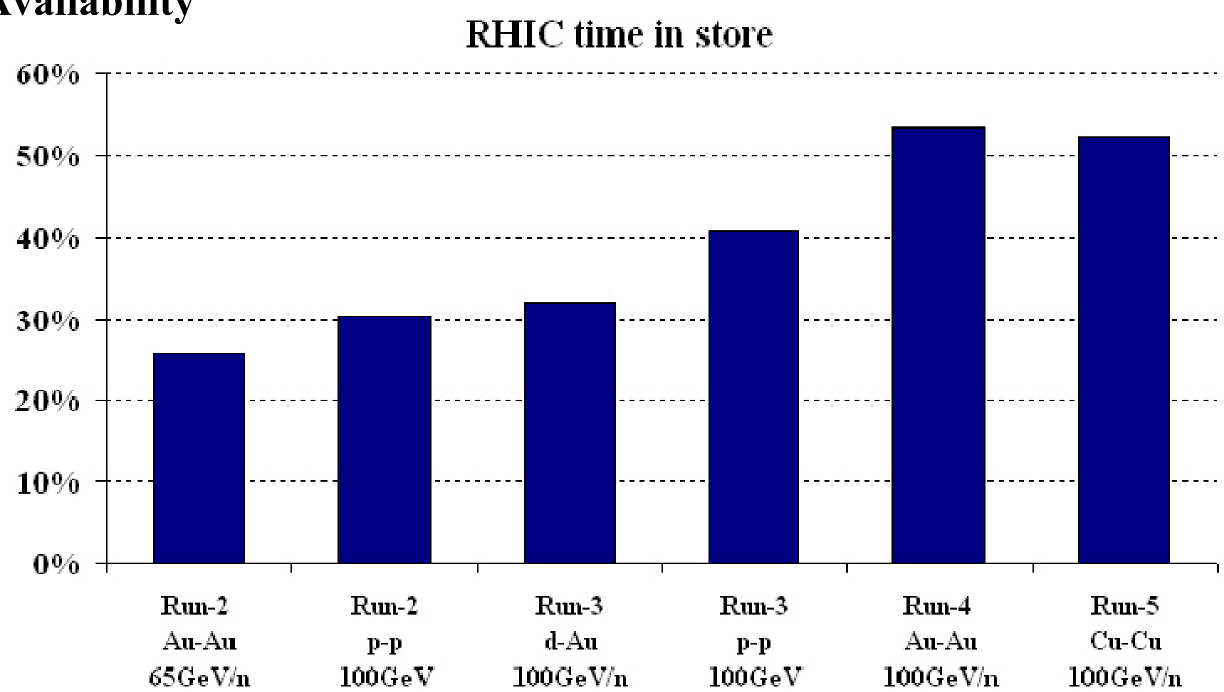
Ongoing investment to improve operating efficiency (cryo upgrade: 2 MW reduction of el. power consumption, EBIS)

RHIC availability and time in store



FY05Q2 Weekly Availability

- Excellent availability despite very complex operation modes.
- Machine set-up time reduced to just 3 weeks.



Connection to other programs

Major contributions from non-DOE sources to the RHIC accelerator complex:

RIKEN, Japan: RHIC Spin (~ $70M, RBRC)

NASA: NASA Space Radiation Laboratory ($4.5M contribution to EBIS)

NSF and Canada: RSVP (construction not started yet, major infrastructure upgrade to Booster and AGS)

Future plans for RHIC

Machine goals for next few years with upgrades in progress:

- **Enhanced RHIC luminosity (112 bunches, $\beta^* = 1$m):**
- **Au – Au: 8×10^{26} cm^{-2} s^{-1} (100 GeV/nucleon)**

2× achieved

- **For protons also 2×10^{11} protons/bunch (no IBS):**
- **p↑ – p↑: 60×10^{30} cm^{-2} s^{-1}; 70 % polarization (100 GeV)**
  150×10^{30} cm^{-2} s^{-1}; 70 % polarization (250 GeV)
  (luminosity averaged over store delivered to 2 IRs)

6× achieved

EBIS (low maintenance linac-based pre-injector; all species incl. U and pol. He3; avoid Tandem investment; ~ 3 year pay-back period)

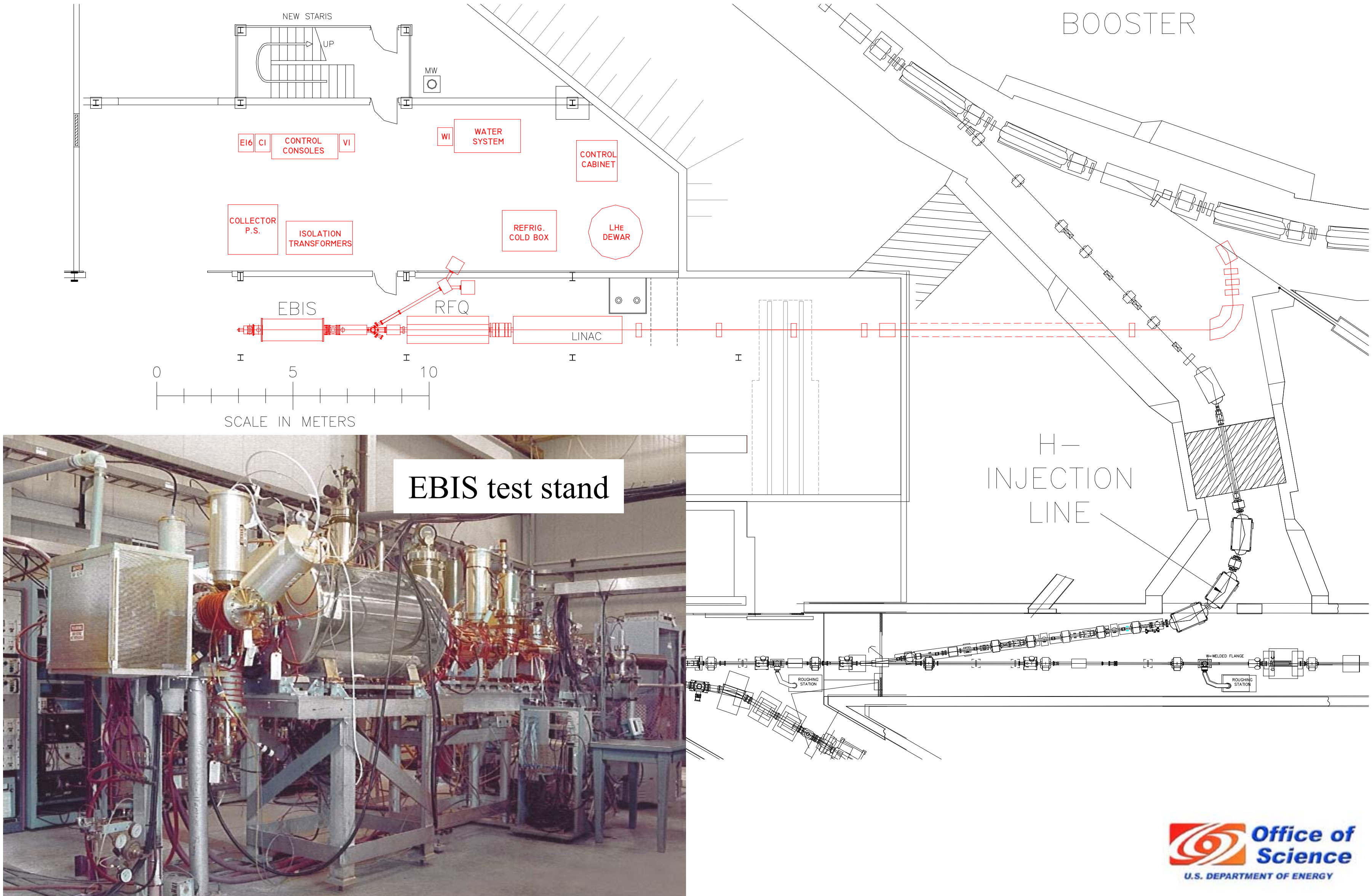
RHIC luminosity upgrade (e-cooling, ~10 × more luminosity, R&D in progress)

eRHIC (high luminosity (1×10^{33} cm^{-2} s^{-1}) eA and pol. ep collider)

EBIS/Linac-based RHIC Pre-Injector

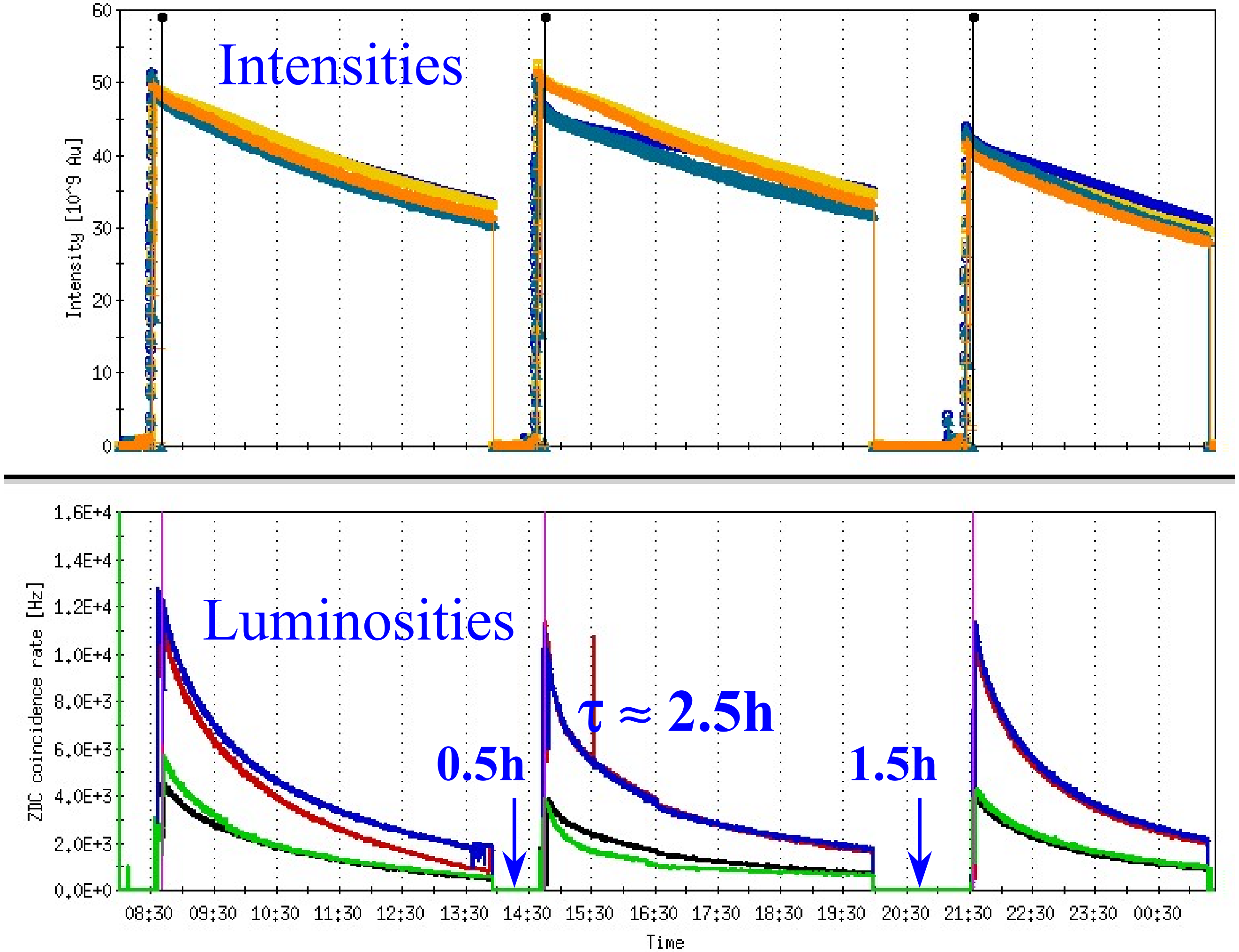
- Highly successful development of Electron Beam Ion Source (EBIS) at BNL: meets RHIC performance requirements.
- EBIS allows for a reliable, low maintenance Linac-based pre-injector replacing the Tandem Van de Graaffs
- Greatly reduced operating costs, and avoidance of ~ 9 M$ in reliability-driven investments in the tandems
- Highly flexible to handle the multiple simultaneous needs of RHIC and NSRL
- Produces beams of ALL ion species including noble gas ions (NSRL), Uranium (RHIC) and polarized He^3 (eRHIC)
- Ready to start construction, CD0 received; Cost: 19.4 M$;
  3.5 year construction schedule: FY2006 – 09
  NASA participation ($ 4.5M)

EBIS layout



EBIS test stand

Luminosity Limit – Intra-Beam Scattering (IBS)



- Debunching requires continuous gap cleaning (tune meter)
- Luminosity lifetime requires frequent refills
- Ultimately need cooling at full energy

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RHIC luminosity upgrade

Eliminate beam blow-up from intra-beam scattering with electron beam cooling at full energy!

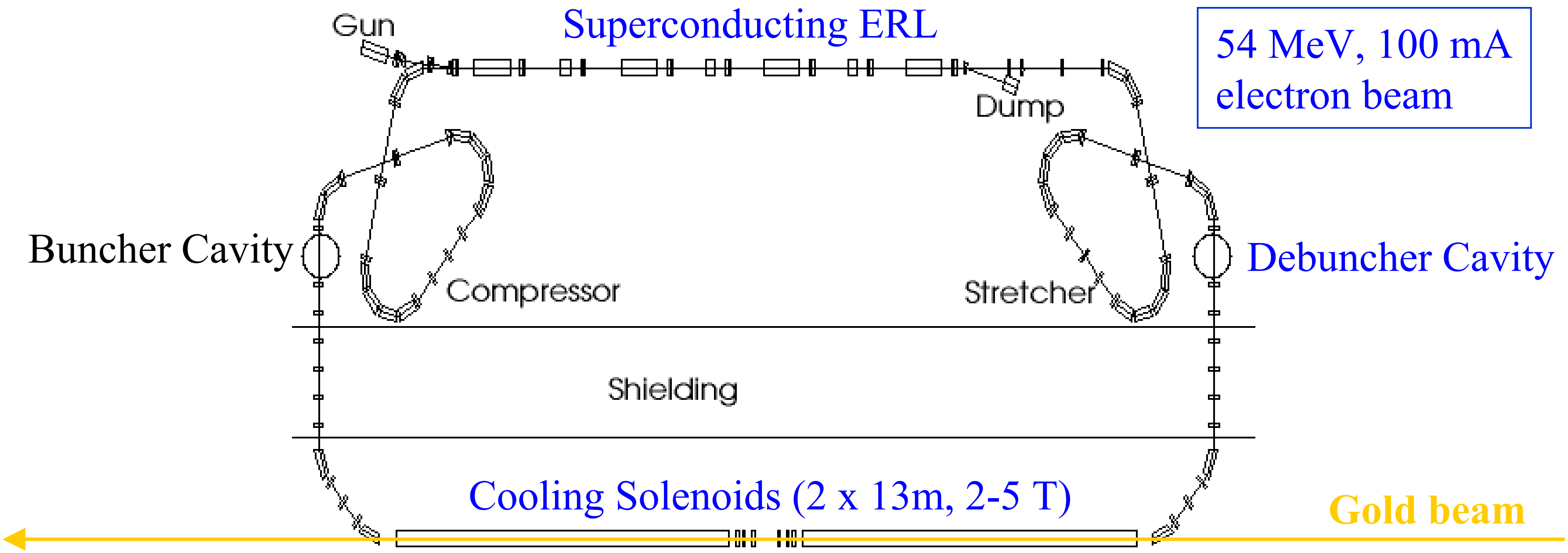
What will remain the same:

- 120 bunch pattern
  - 100 ns collision spacing (~ same data acquisition system)
  - Only one beam collision between DX magnets
- 20 m magnet-free space for detectors
  - No “mini-beta” quadrupoles
- Approx. the same bunch intensity
  - No new beam intensity issues
  - Background similar as before upgrade

What changes:

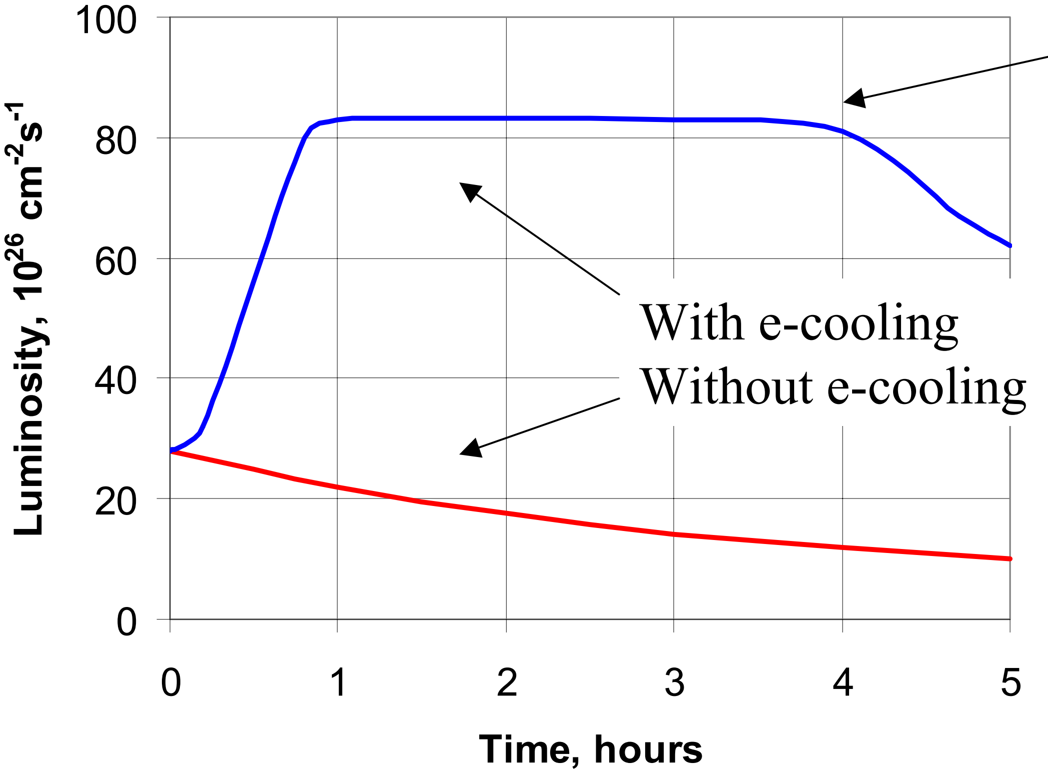
- Smaller transverse and longitudinal emittance
  - Smaller vertex region (Increased luminosity within detector acceptance)
- Beta squeeze during store to level luminosity
- Store length is limited to ~ 5 hours by “burn-off” due to Au-Au interactions (~ 200 b)

Electron Cooling R&D



- Benchmarking of IBS and cooling simulation codes
- Demonstrate high precision (<10 ppm) solenoid (2-5 T)
- Demonstrate 20 nC, 100-200 mA 703.8 MHz CW SCRF electron gun
- Develop 703.8 MHz CW superconducting cavity for high intensity beams
- Build R&D Energy Recovering Linac (ERL)

Electron cooling simulations

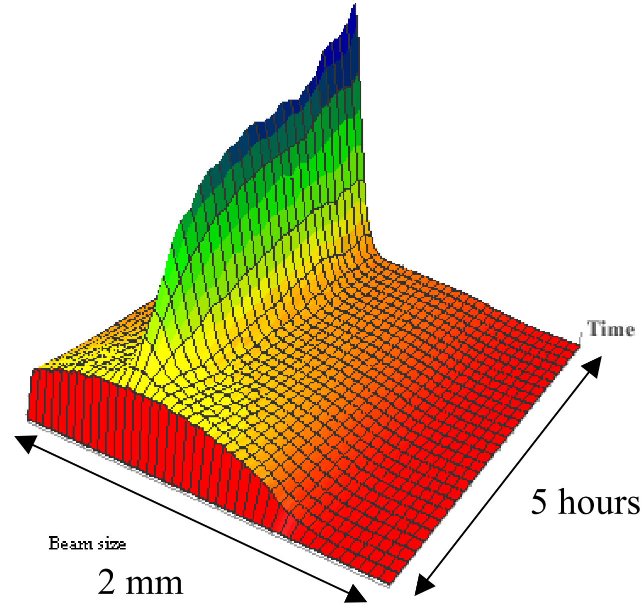


Luminosity leveling through continuously adjusted cooling

Store length limited to 4 hours by "burn-off"

Four IRs with two at high luminosity

Transverse beam profile during store



Also able to pre-cool polarized protons at injection energy

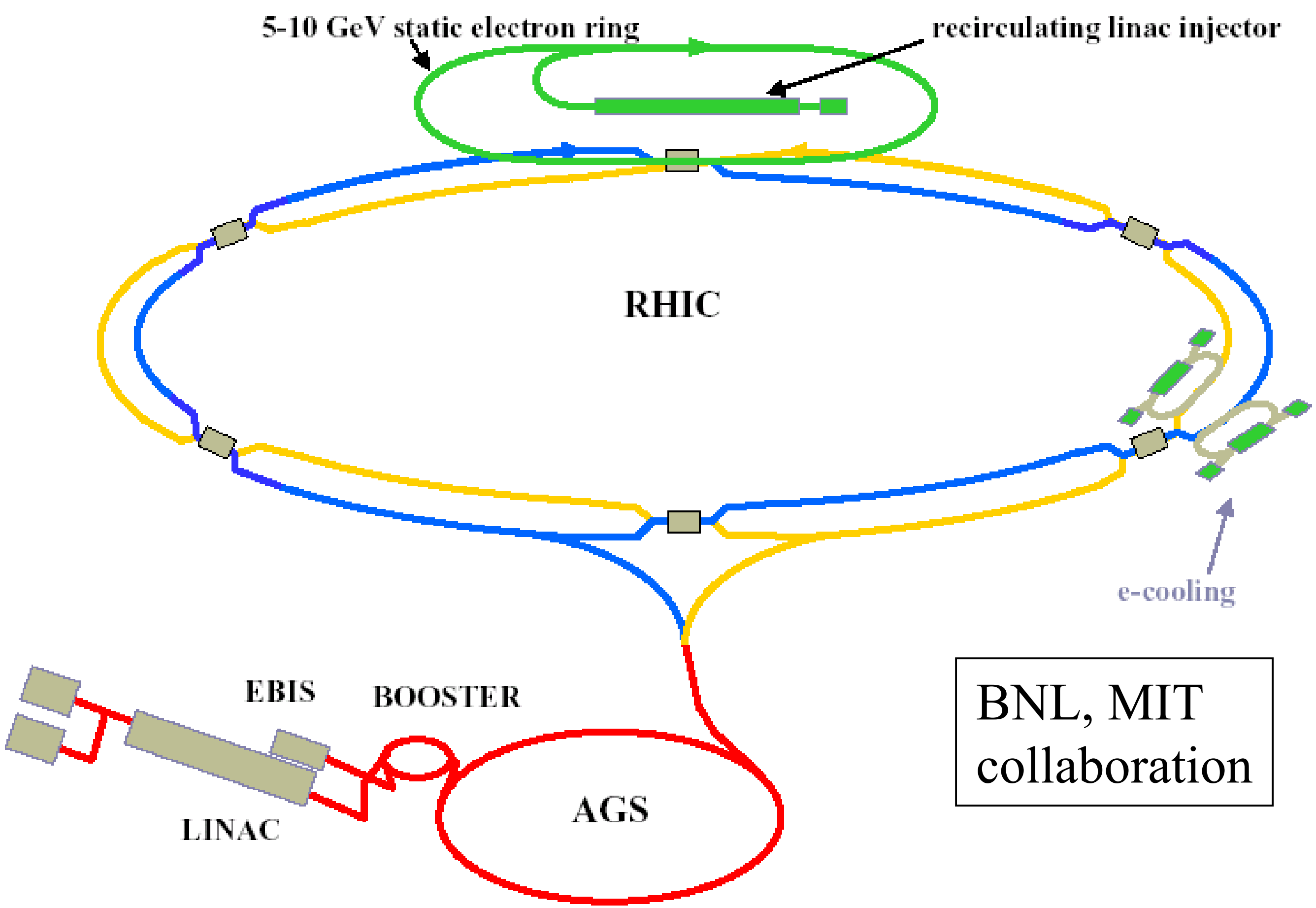
RHIC Luminosity Upgrade with Electron Cooling

Gold collisions (100 GeV/n x 100 GeV/n):	**w/o e-cooling**	**with e-cooling**
Emittance (95%) $\pi\mu m$	$15 \rightarrow 40$	$15 \rightarrow 3$
Beta function at IR [m]	1.0	$1.0 \rightarrow 0.5$
Number of bunches	112	112
Bunch population [10^9]	1	$1 \rightarrow 0.3$
Beam-beam parameter per IR	0.0016	0.004
Ave. store luminosity [10^{26} cm^{-2} s^{-1}]	8	70

Pol. Proton Collision (250 GeV x 250 GeV):		
Emittance (95%) $\pi\mu m$	20	12
Beta function at IR [m]	1.0	0.5
Number of bunches	112	112
Bunch population [10^{11}]	2	2
Beam-beam parameter per IR	0.007	0.012 ?
Ave. store luminosity [10^{32} cm^{-2} s^{-1}]	1.5	5.0

Electron-Ion Collider at RHIC: eRHIC

- 10 GeV, 0.5 A e-ring with 1/3 of RHIC circumference (similar to PEP II HER)
- 10 GeV electron beam $\rightarrow s^{1/2}$ for e-A : 63 GeV/u; $s^{1/2}$ for e↑-p↑: 100 GeV
- Electron cooling required for high luminosity e-A and low energy e-p collisions
- Polarized e-He3 (e-n) collisions with EBIS
- Existing RHIC interaction region allows for typical asymmetric detector
- Luminosity: up to 1×10^{33} cm^{-2}s^{-1} per nucleon (1×10^{34} cm^{-2}s^{-1} with linac – ring scheme)



BNL, MIT collaboration

Summary

Since 2000 RHIC has collided, for the first time,

- Heavy ions
- Light on heavy ions
- Polarized protons (45% beam polarization)

Heavy ion luminosity increased by factor 100

For next 4 years planned:

- Factor 2 increase in heavy ion luminosity
- Factor 6 increase in proton luminosity
- Factor 2 increase in proton beam polarization

Future upgrades:

- RHIC luminosity upgrade (~10x) using electron cooling at store
- Electron-ion collider eRHIC

Back-up material

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RHIC design, achieved and enhanced design parameters

Mode	No of bunches	Ions/bunch $[10^9]$	β* [m]	Beam polarization	L_{peak} $[cm^{-2}s^{-1}]$	$L_{store\ ave}$ $[cm^{-2}s^{-1}]$	$A_1A_2L_{store\ ave}$ $[cm^{-2}s^{-1}]$
Design values (1999)							
Au – Au	56	1.0	2		8×10^{26}	2×10^{26}	8×10^{30}
p – p	56	100	2		5×10^{30}	4×10^{30}	4×10^{30}
Achieved values (2004)							
Au – Au	45	1.1	1		15×10^{26}	4×10^{26}	16×10^{30}
p↑ – p↑	56	70	1	45%	5×10^{30}	4×10^{30}	4×10^{30}
p – p	56	170	1		15×10^{30}	10×10^{30}	10×10^{30}
Enhance design values (2008)							
Au – Au	112	1.1	1		30×10^{26}	8×10^{26}	31×10^{30}
p↑ – p↑	112	200	1	70%	80×10^{30}	65×10^{30}	65×10^{30}

$$\boxed{L = \frac{3 f_{rev} E}{2M} \frac{N_B N^2}{\varepsilon \beta^*}}$$

Other high luminosity hadron colliders:

	achieved	goal	scaled to 200 GeV
Tevatron (2 TeV)	100×10^{30}	200×10^{30}	20×10^{30}
LHC (14 TeV)		10000×10^{30}	140×10^{30}

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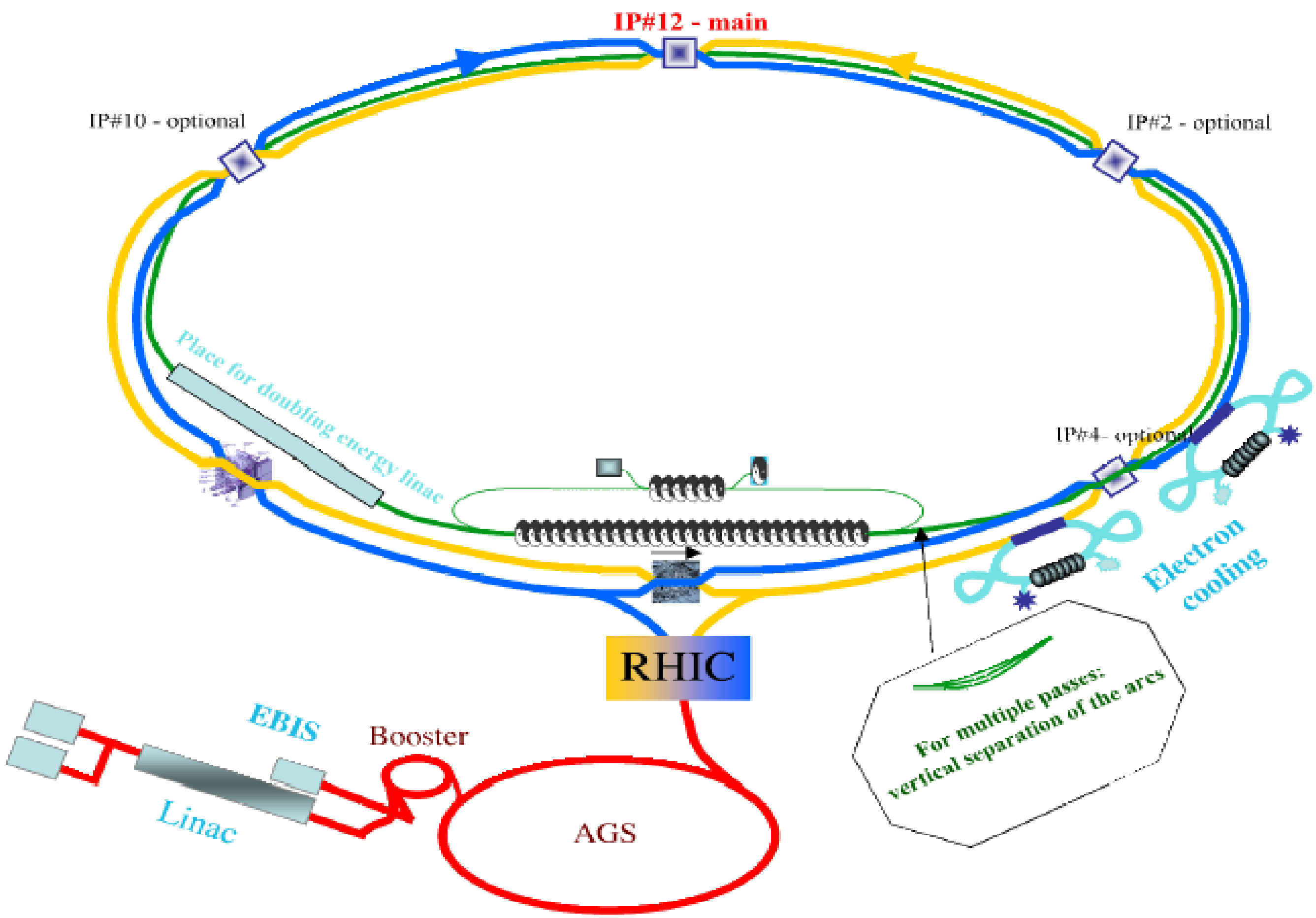
Alternative eRHIC Design: Linac - Ring

Electron ring replaced by energy-recovering linac, electrons in RHIC arcs: Higher luminosity (1×10^{34} cm^{-2}s^{-1}), simpler IR design, multiple IRs possible, 20 GeV upgrade possible



NP Operations scenarios: cryo-weeks

Scenario	FY06	FY07	FY08	FY09	FY10	FY11	FY12
Flat 2006, with EBIS constr.	12	12	0	12	18	24	...
Flat 2006, without EBIS constr.	20	13	13	13	20	20	
Flat-flat (**without** EBIS)	20	6	7	3	"lights out"		
Flat 2005	31	31	31	31	31	31	

> 20 cryo-weeks
< 20 cryo-weeks

EBIS Completion

Impact of FY2006 Presidential on Accel. Ops.

FY06 cryo-weeks reduced from 31 to 12 weeks

- Combine FY06-07 runs for some models. Avoid summer running. Begin on 10/1/06 after 15 month shutdown.
- $300K (ions) - $325K (polarized proton) / week running and $75K / week power costs when off
- EBIS construction is expedited. Funding increased from $2.0M to $3.6M (+ $1.5M from NASA). Reprogram AIP ($0.5M), capital ($0.7M + $0.4M)

Operations manpower reductions of 30-34 FTE (355->325-321 FTE)

- The efficient and safe operation of the accelerator complex with the proposed staff size is more difficult. <u>Present</u> staff workload and stress levels are high. Concern that key accelerator physicists will move across the Atlantic. Loss of expertise is a major issue.
- Some staff would be assigned to RSVP, if funding arrives in time.

Electron cooling R&D will be reduced as EBIS takes priority and RHICII recedes into future

Reassign waste management funding. 50% used to support FY06

Impact of FY06P + constant effort (flat) funding on Accel. Ops.

Combined FY06-07 run.

With EBIS:

- Reprogram funds to complete EBIS project (FY06-09).
- No run in FY08
- Combined FY09-10 run.
- Yearly 24 cryo-weeks running FY11 and later. Reduced operations cost form EBIS completion allows for more running.

Without EBIS:

- Reprogram funds to complete Tandem reliability upgrade (FY07-09)
- Combined FY08-08 run
- Yearly 20 cryo-weeks running FY10 and later

The efficient and safe operation of the accelerator complex with the staff size is more difficult.

This funding model supports the most favorable but still a dwindling long term physics program

Impact of FY06P + "flat-flat" on Accel. Ops.

EBIS will not be built.

Flat-flat funding would only allow for a combined FY06-07 and a combined FY08-09 run and then unable to support a physics program thereafter.

Loss of expertise to complete the proposed runs is significant.

The efficient and safe operation of the accelerator complex with the FY06 staff size is more difficult.

This funding model rapidly leads to RHIC termination.

BNL proposed (FY2005 + constant effort)

31 cryo-week each year

- Physics program includes ions and polarized protons to 500 GeV cm.

EBIS project completed in 3.5 years

- Reduce injector group manpower

Accelerator R&D support of electron cooling for future RHICII and eRHIC would remain on a fast track.

AIP support to continue to replace aging machine components and improve performance, eg. RHIC cryogenic system is 25 years old, would be accomplished in an orderly manner.

RHIC running efficiency and safety are not a concern.